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THE CARBON ABUNDANCE OF POPULATION II STARS

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Curve of growth analyses available to date for Population II stars have indicated that carbon is more deficient relative to the sun than iron. A refined treatment, which takes into account stratification and molecular equilibrium, shows that carbon is not more deficient than iron, assuming a solar oxygen-to-iron ratio.

The abundance in subdwarfs of the light elements carbon, nitrogen and oxygen cannot be deduced from their atomic spectra; the molecular spectra must be used. From an analysis of the CH band in two high velocity stars, HD 6755 and HD 103095 (Groombridge 1830), the carbon abundance is found. In both cases the carbon to iron ratio is close to or larger than the solar value.

The atmosphere and abundance programs of Strom *et al.* (1966), with a treatment of molecules described in Cohen and Strom (1968) were used. In analyzing the molecular spectrum, we solve the equations of molecular equilibrium for 34 optical depths in the atmosphere. The procedure used is applicable to any diatomic band system with known oscillator strengths where individual rotational lines can be resolved. Since no information on the oxygen abundance in these stars is available, we take the oxygen-to-iron ratio to be the solar value.

A differential curve of growth analysis of HD 6755, a high-velocity K giant, has recently been made by Koelbloed (1967), who used plates taken by J. L. Greenstein at dispersions of 9 and 14 Å/mm. We use Koelboed's equivalent widths. In his analysis, an effective temperature (T_{eff}) of 5200°K and a surface gravity $\log g = 2.8$ were used for HD 6755, with the metals reduced in abundance by a factor of ten, as compared with the sun. The corresponding model atmosphere we denote by (5200, 2.8, 0.1). A microturbulent velocity of 1 km/sec was obtained.

From an analysis of eight CH lines and one CN feature, using a method suggested by Schadee, who later was not certain of its validity (Schadee 1968), Koelbloed derived deficiencies with respect to the Sun of C, N, and O which were a factor of two or three larger than the mean deficiency of the metals. For these, a uniform deficiency of approximately a factor of ten with respect to the Sun was found, with slight variations among the heaviest elements. Such a situation would be rather difficult to understand with current conceptions of chemical abundances at the early stages of galactic evolution.

There is considerable uncertainty in the selection of parameters applicable to the model atmosphere describing HD 6755. Although a continuum scan corrected for blanketing from 3570 to 5890 Å is available, it is possible that the star is reddened. The scan given by Koelbloed, corrected to the new calibration of Vega by Hayes (1967), when fitted to model atmosphere calculations gives an effective temperature of close to 5200°K. Hence we adopt 5500°K as an upper limit to T_{eff}. A model (5500, 3.0, 0.1) gives satisfactory ionization equilibrium for Fe, Ti and V, which is probably the most reliable method of obtaining T_{eff} for such a star. Because of the large scatter, we did not try to evaluate the microturbulent velocity; we have adopted $v_t = 1$ km/sec.

However, the one feature attributed on CN by Koelbloed (λ4159.19 Å) coincides with the R 25 (0, 0) rotational line of the $A^2\Delta - X^2\pi$ CH band (Moore and Broida 1959). In *The Solar Spectrum 2935 to 8770* Å (Moore *et al.* 1966), this feature is interpreted as partially CH, with the dominant contributor unidentified. It seems unlikely that CN is the principal contributor since the line is much larger than any nearby CN feature. Hence, in HD 6755 only the CH lines are suitable for use. Under such circumstances, since no information on the oxygen abundance is available, we take C, N, and O to be deficient by a factor of ten with respect to the Sun, and see if the predicted CH line strengths are compatible with the observed equivalent widths of CH lines. For the (5500, 3.0, 0.1) model, we obtain $\log(N_{\text{C}}/N_{\text{H}})_{6755} - \log\,(N_{\text{C}}/N_{\text{H}})_{\odot} = -0.94 \pm 0.2$ while the metals are deficient by a factor close to ten. (The Sun is used as a standard star throughout.) For the cooler model (5000, 3.0, 0.1) the carbon deficiency is larger, but the iron deficiency also increases by approximately the same factor. Hence, it seems clear that in HD 6755, as in all metal-deficient stars studied with a refined analysis, a possible solution is that carbon and oxygen are not more deficient than the iron-peak elements.

In the course of the investigation, we have re-examined also the abundance of the heavy elements past the iron peak in HD 6755. This was thought necessary since many of the lines used by Koelbloed are seriously blended. Of the four La II lines used in the curve of growth analysis, $\lambda4238.40$ is blended with a CH line, and $\lambda4333.76$ is probably blended with $\lambda4333.90$ (unidentified in the Sun) at the low dispersion of the plates. Similar remarks are true to a lesser extent for most of the other heavy elements with few observed lines. The elimination of the blends in effect decreases the abundance of the heavy elements below that obtained by Koelbloed; however, the approximation made in the 'grobe' analysis that $\Delta\theta$ is the same for neutral and for ionized lines appears to cancel out the effect of the use of blended lines. Thus the final results of the detailed model atmosphere analysis are essentially the same as those of Koelbloed. Although it is difficult to find any lines at all of the heavy elements (which are of the greatest interest with regard to theories of element formation during the history of the Galaxy) in extremely metal deficient stars, great caution is required to avoid lines which are too blended to be useful.

For HD 103095, the equivalent widths of Jugaku and Greenstein (1960, private communication) have been used. The effective temperature of Groombridge 1830 deduced from the continuum is close to 5000°K (Strom *et al.* 1967). Cayrel (1968) obtains $T_{\mathrm{eff}} = 5000$°K from ionization equilbria of Fe, Ti and G, assuming $\log g = 4.5$. Therefore we feel justified in adopting the model (5000, 4.3, 0.1). With this model, from seven unblended lines of the $A^2\Delta - X^2\pi$ CH band we obtain

$$\log(N_{\mathrm{C}}/N_{\mathrm{H}})_{103095} - \log(N_{\mathrm{C}}/N_{\mathrm{H}})_{\odot} = -1.2 \pm 0.2.$$

Although no detailed analysis of the iron lines has been made, Groombridge 1830 has a very large ultraviolet excess (δ (U–B) = 0.19). From Wallerstein's (1962) correlation between ultraviolet excess plus metal deficiency, we obtain an iron deficiency of approximately a factor of 15, so that for HD 103095, the carbon-to-iron ratio is close to the solar value.

Throughout, we have assumed a solar oxygen-to-iron ratio. The actual carbon abundance cannot definitely be obtained by any technique using only observations of the CH band, until some information on the oxygen content is available, probably from an analysis of the CO bands in the infrared. Such observations would be extremely useful. (If, as some investigations suggest, the oxygen to iron ratio is higher than its solar value, the carbon abundance will also be higher.)

The CH bands in four metal deficient stars, HD 19445, HD 140283 (Cohen and Strom 1968), HD 6755, and HD 103095, have been examined with a detailed analysis to obtain the carbon abundance. Although in the three stars which previously had been analyzed by curve of growth techniques, carbon was found to be more deficient than iron, more refined analyses show that carbon is approximately as deficient as iron. Thus detailed abundance analyses seem to indicate that population II stars which have metal deficiencies ranging from a factor of 10 to 100 show, with slight variations, solar abundances scaled by a constant factor, except perhaps for a slightly larger deficiency of the heavy elements past the iron peaks.

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